Army Research Laboratory

A Dihedral Sample Mount for Off-Normal RAM Performance Measurements

by Robert B. Bossoli

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A Dihedral Sample Mount for Off-Normal RAM Performance Measurements

Robert B. Bossoli
Weapons and Materials Research Directorate, ARL

Abstract

A novel sample mount has been designed for making high angle of incidence radar-absorbing material (RAM) sample performance measurements. The sample mount allows for ~47° angle of incidence measurement of RAM millimeter-wave (MMW) reflectivity (performance). Measurements are taken from 26–60 GHz and 75–100 GHz in the U.S. Army Research Laboratory's (ARL) Weapons and Materials Research Directorate (WMRD) Composites and Lightweight Structures Branch (CLSB) anechoic chamber. RAM samples can also be mounted in a full dihedral configuration for simulation of RAM performance in double bounce (corner)-type locations. Performance of two commercial-type RAM materials was measured at close to normal and at the ~47° off-normal angles of incidence. A full dihedral covered with one of the commercial RAMs was also tested. The mount will allow for more realistic evaluation of ARL- and contractor-designed RAM and other coatings to be utilized in low-observable Army and Department of Defense (DOD) projects.

Acknowledgments

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1. Introduction

Numerous types of radar-absorbing materials (RAM) have been developed over the past 50 yr in response to try to defeat radar deployed on the battlefield and on naval vessels. Only recently, however (past 10 yr), has the technology developed to the point where it can be effectively incorporated into military systems. The stealth fighters (F-111 and F-22 Raptor) and the stealth bomber (B-2) are two well-known examples of military systems where RAM technology has been incorporated into their design. The development of smaller millimeter-wave (MMW) components with the required power output has led to their incorporation into battlefield surveillance and tracking radar and into smart munitions. This new, higher frequency band radar can offer a variety of threats, ranging from detection to destruction of currently fielded Army vehicles and structures. RAM and radar-absorbing coatings (RACOs) are designed to reduce the radar reflection over various important (threat) bands of radar frequencies. Their performance is tested for normal (90°) or close to normal angles of incidence of the radar beam with respect to the RAM surface. For systems with complex angles and shapes, such as on ships, trucks, and other vehicles, radar returns are usually a result of double or triple bounce (reflections) back to the transmitting radar. A sample mount simulating the two-surface double bounce (dihedral configuration) has been designed and built for the microwave measurement range of the U.S. Army Research Laboratory's (ARL) Weapons and Materials Research Directorate (WMRD) Composites and Lightweight Structures Branch (CLSB) Materials Physics Team. This paper describes the mount and the measurement procedure, along with some experimental performance results for commercially available microwave-absorbing materials. Dihedral performance data for the team's SECRET/SAP materials under development by the group will be presented in a separate future report.

2. RAM Reflectivity Test Setup

2.1 Standard RAM Performance Measurement System. Figure 1 shows a diagram of the standard ARL-RAM performance measurement setup, where the angle of incidence is almost normal to the sample with the radar horns in a bistatic (~10°) configuration. Sample sizes are

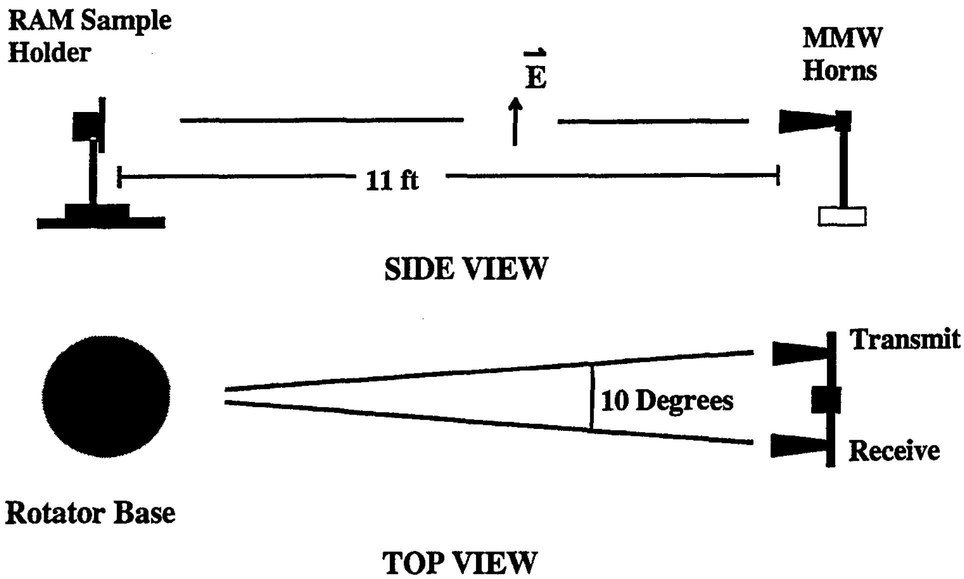
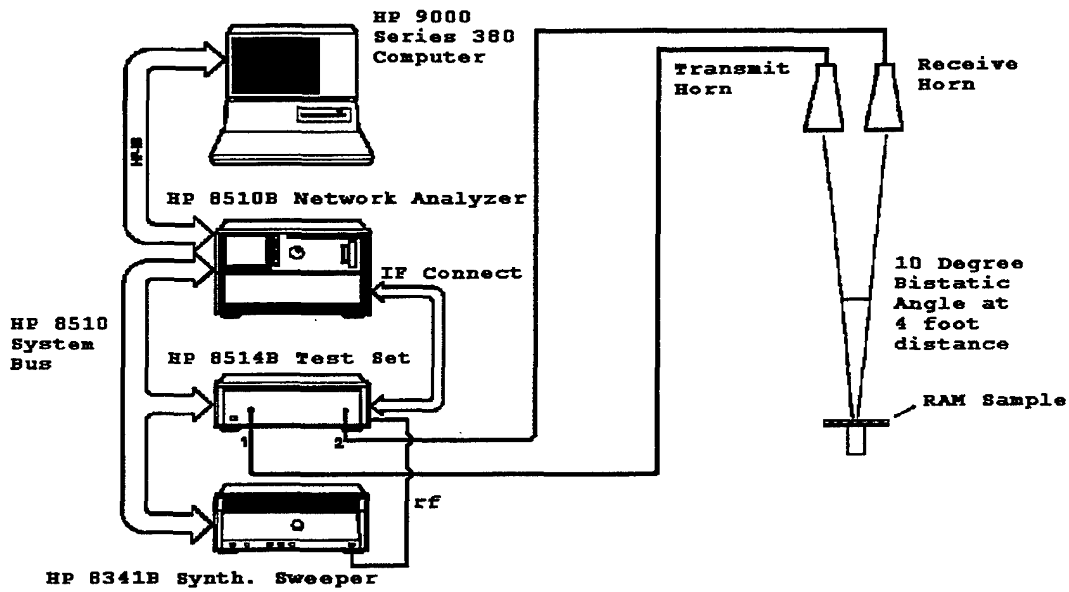


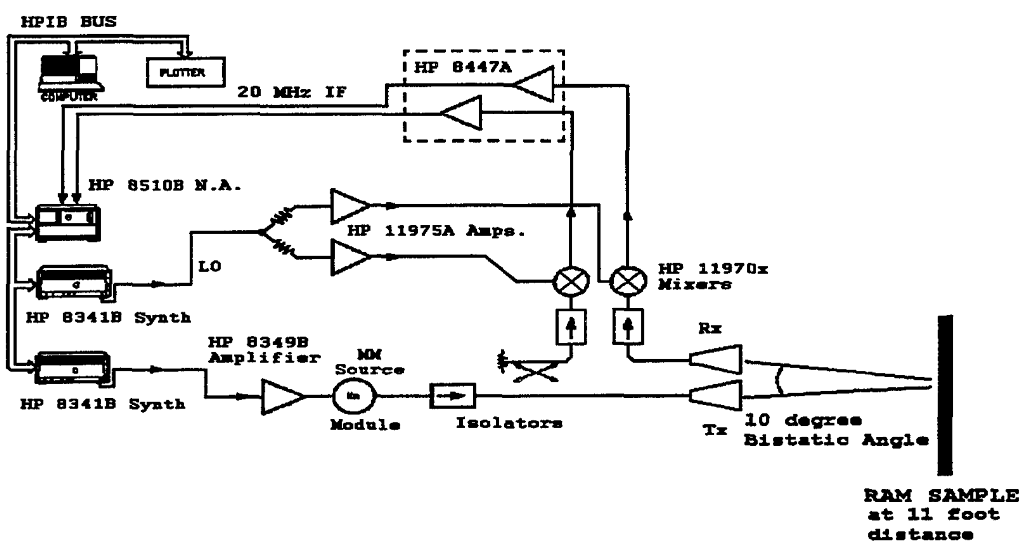
Figure 1. Bistatic RAM Sample Performance Measurement Configuration.

usually 6 × 6 in or 12 × 12 in, and the radar performance is referenced to a metal plate of the same dimensions. The Materials Physics Team RACO measurement system employs a Hewlett Packard (HP) 8510B microwave network analyzer with sweepers and MMW modules, allowing RAM and RACO performance measurements in the 2–20-, 26–40-, 40–60-, and 75–100-GHz frequency bands. Block diagrams of the microwave and MMW equipment configurations are shown in Figures 2(a) and (b), respectively. The system uses linearly polarized microwave or MMW transmit and receive horns with a ±10° bistatic angle (5° angle of incidence). The low-frequency (2–20 GHz) horns are configured in an arch-type configuration, allowing the bistatic angle to be changed by 10° increments from 10–50°. A single horn can be employed to transmit and receive in the low-frequency band, performing true normal (0° angle of incidence) reflectivity measurements if required.

Figure 3 shows a photo of the standard (single bounce) sample mount, along with a photo of the bistatic MMW horns and HP network analyzer covering the high-frequency 26–40-, 40–60-, and 75–100-GHz frequency bands. The RAM samples are mounted on 6- × 6-in metal backing plates and replace the reference metal plate, as seen in the left-hand photo in Figure 3. They are held in place by a double-stick tape and a lip on the bottom edge of the mount.



(a)



(b)

Figure 2. System Configuration Diagrams for (a) Microwave and (b) MMW RAM Sample Performance Measurements.

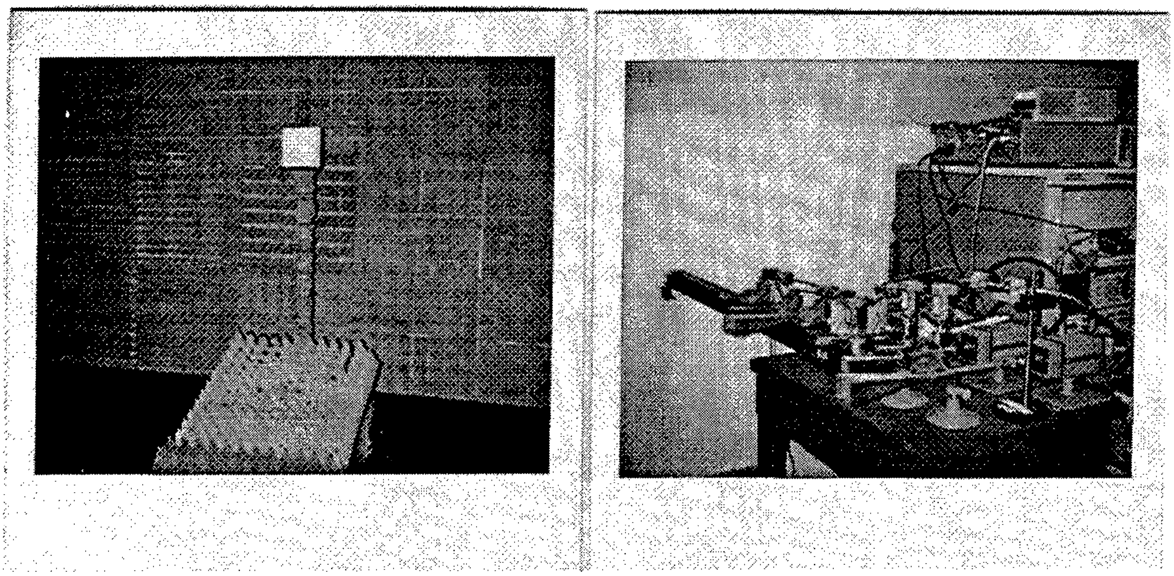


Figure 3. Photos of the Standard RAM Sample Mount (Left) and the MMW Bistatic Measurement System (Right).

2.2 Dihedral RAM Performance Mount Design. Figure 4 shows a close-up photo of the dihedral sample mount that replaces the standard single-bounce "normal incidence" sample mount (shown in Figure 3) for high-frequency (26–40, 40–60, and 75–100 GHz) MMW measurements. The mount consists of two 6-× 6-in plate holders joined at one edge, with the angle between them at approximately 90°. One of the plate holders is adjustable in angle, so the angle between the two holders is variable from about 80–110°. For a monostatic radar, the maximum return for a double-bounce (dihedral) configuration is for the plates oriented at a 90° angle [see Figure 5(a)]. However, as shown in the diagram in Figure 5(b) for a 10° bistatic configuration, the optimum angle for double-bounce returns for the plates on the "dihedral" mount is 95°. The dihedral measurement sample fixture is attached to a azimuthal rotator on the floor via a 4-ft pipe, which enables the alignment for the a symmetric double bounce back to the radar horns, as depicted in Figure 5(b).

2.3 RAM Measurement Procedure Using Dihedral Sample Mount. In order to measure a sample or pair of samples of the same design in the of angle dihedral configuration, the mount

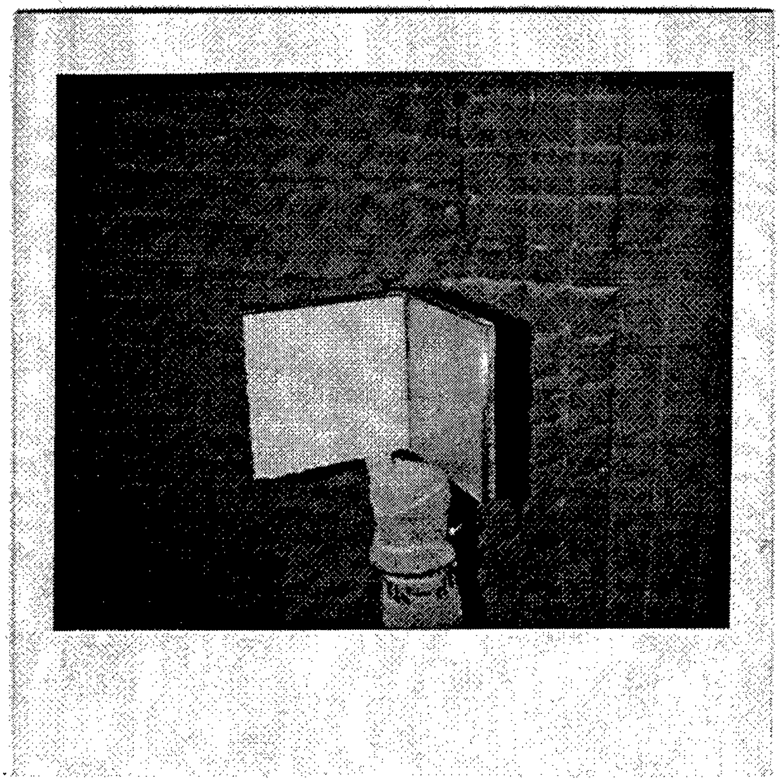
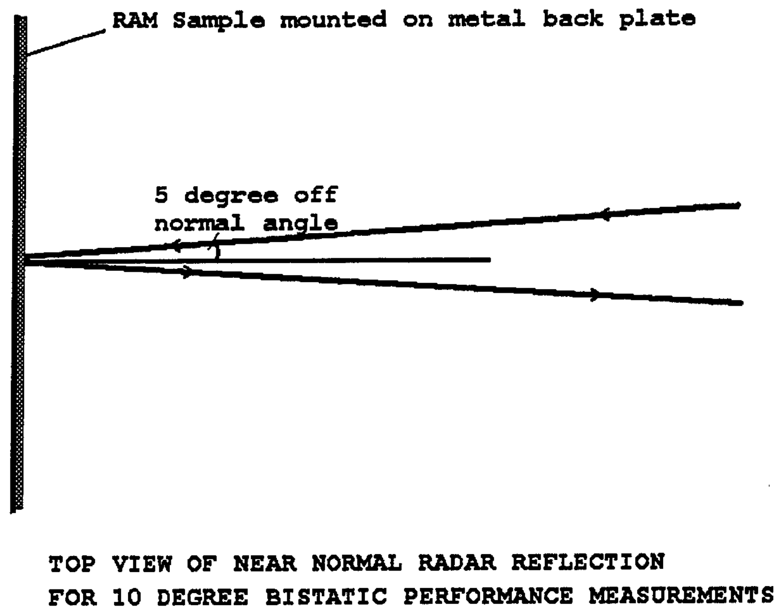


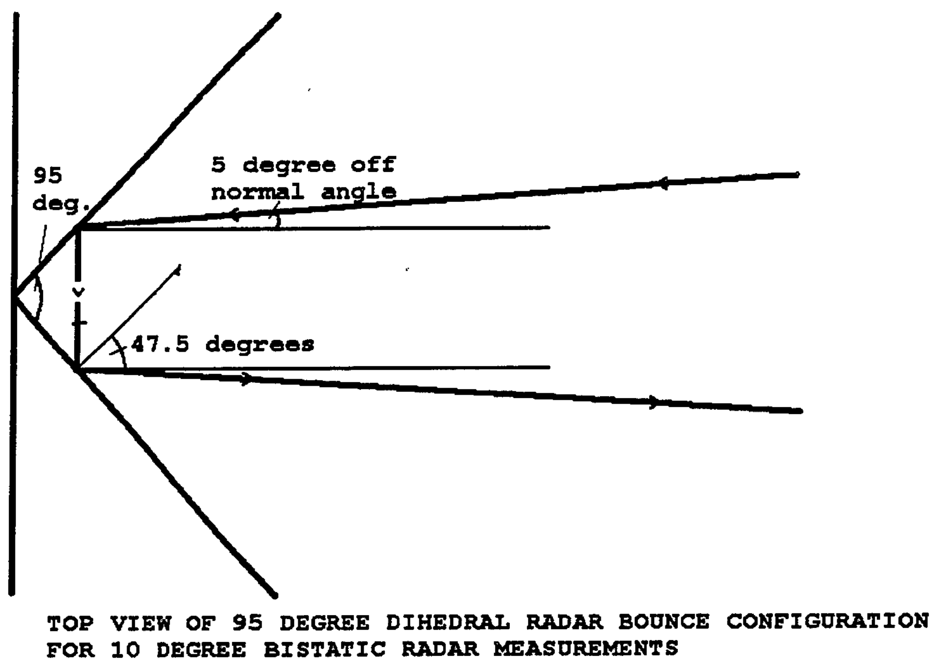
Figure 4. Photo of the Dihedral RAM Performance Sample Mount.

must be aligned (rotated) to give proper orientation as detailed previously. With two 6- × 6-in bare aluminum sample plates placed in the dihedral sample mount, it is rotated so that one of the plates is oriented for maximum reflection at near-normal incidence [as in Figure 5(a) for the 10° bistatic angle of the radar horns] and the rotator is reset to read 0°. Since the angle between the dihedral is 95°, the rotator must be rotated (180–95)/2°, or about 42.5°, to correctly orient the dihedral mount [as depicted in Figure 5(b)] for making the off-normal-incidence measurements. When the frequency is switched to another frequency band with different pair of transmit/receive horns, this alignment procedure must be repeated.

After the dihedral mount is aligned, the microwave network analyzer (NWA) is programmed to take a reference set of data with two bare metal reference plates in position on the mount. These data are stored into the NWA memory, and utilizing the divide-by memory function will be the reference data to which the subsequent measured data are compared. For the large



(a)



(b)

Figure 5. Top View of Path of Radar Wave for (a) Standard and (b) Dihedral RAM Sample Mounts.

off-angle (~47° incidence), RAM performance measurements, the sample (mounted on a 6- × 6-in metal sample plate) is put in place of one of the bare metal sample plates. When the data are taken (division by the reference data) in log format, the performance of the RAM at the ~47° angle of incidence is measured. Since, in this configuration, the edges of the plates are facing toward the microwave horns, small strips of commercial RAM (Advanced Absorber Products [AAP]-type ML-73) are sometimes placed on the plate edge facing the transmit horn to help reduce scattering back to the receiver horn. However, in general, there is much more noise and interference effects in the data due to the orientation and scattering off of the edges of the plates in the dihedral measure configuration, as compared to the normal-incidence data. For a test of a double-bounce performance of a type of RAM material, two samples mounted on 6- × 6-in metal plates, or mounted on the dihedral holder and the reflection measurement performed, again referenced the bare-plate dihedral data. In this case, the results mimic what a RAM-coated corner reflector would reflect back to a radar or what a double bounce off two RAM-covered surfaces orientated at ~45° would attenuate the incident radar signal.

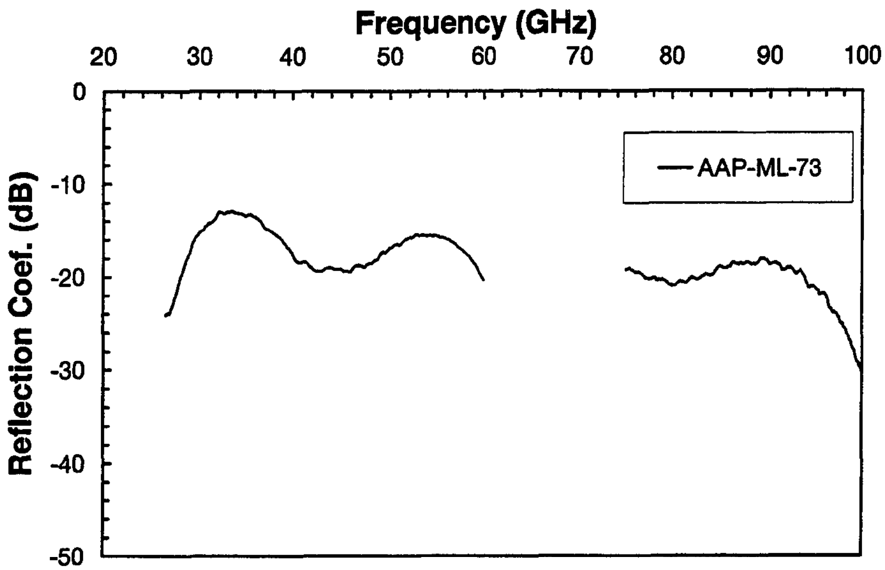
3. Experiment Results for Commercial RAM

The performance (reflection coefficient) of two different types of commercial RAM samples was measured. The first type is a black-colored net or mesh-like material approximately 3/4 in thick, made by General Atomics. It has a copper-coated, highly conductive portion (bottom 1/8 in), which acts as a ground plane preventing any radar penetration. The fact that the material is mostly air and is a thick netting with a mesh-like construction makes it highly probable that it will scatter a substantial portion of the incident radar signal in all directions, as well as absorbing the signal. The net will have low reflection off the front surface since it is irregular, and radar waves will be absorbed and/or scattered by it, depending on the resistivity of the net material or its surface coating. This enables it to be an effective absorber/scatterer over a wide-frequency range. The drawbacks of this design are that it will probably be much less effective in an outdoor environment due to moisture/water penetration.

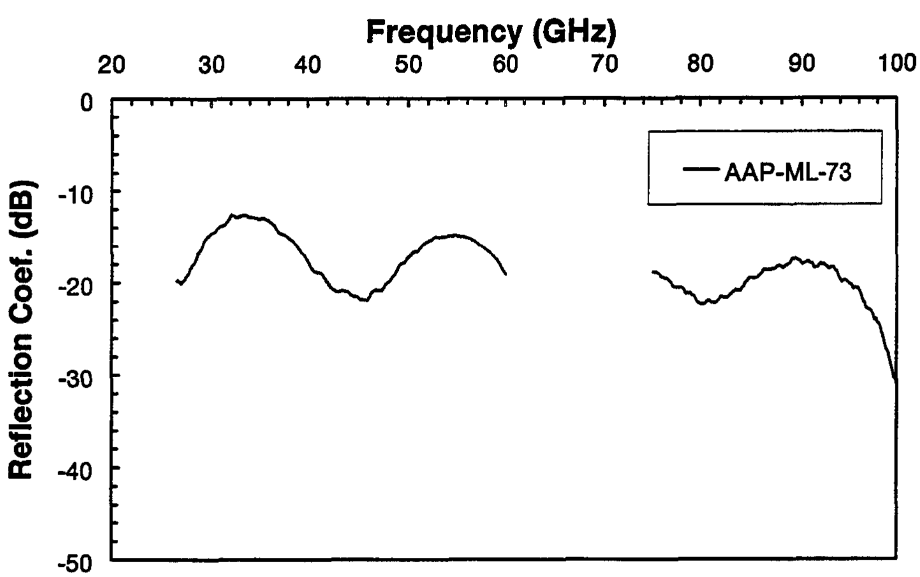
The second type of commercial RAM sample is a carbon-loaded, lightweight, multilayer foam material manufactured (type ML-73) by AAP. It has a total thickness of 1.1 cm, with each layer (probably with different carbon loading) having a thickness of about 3.5 mm. This material utilizes the resistivity of the carbon particles to absorb a portion of the radar signal. Since it has a fairly flat front surface, the material will probably exhibit some broad absorption peaks where it has some destructive interference occurring between radar waves reflected off the front surface and those making it through the material after reflecting off the backing plate. The material has a blue spray paint outer layer to help prevent mechanical deterioration during handling. This material, again, is not very effective outdoors in a wet environment since the light carbon-loaded foam material is not very durable and would also absorb water, affecting its radar-absorbing ability. The material is flexible, can be wrapped around objects and mounts to prevent radar returns, and is mainly utilized indoors in anechoic chambers designed for radar and antenna tests.

3.1 Performance Results on a Standard Mount With a 10° Bistatic Angle. Measurements were first made on the two commercial absorbers with the standard RAM sample mount at close-to-normal incidence (5°). The performance measurements from 26.5 to 100 GHz for the AAP absorber sample are shown in Figure 6. The parallel data refer to the orientation of the microwave E-field vector with respect to one chosen side of the square 6- × 6-in sample. The perpendicular data refer to the sample rotated 90° and replaced on the mount so the microwave E-field is perpendicular to the chosen side of the sample. Due to the design and composition of the two commercial RAM samples, they should not exhibit any anisotropy in their performance for each orientation with respect to the microwave electric field (E-field) vector polarization. The parallel and perpendicular data (Figure 6) for the AAP sample exhibit essentially the same reflection coefficient.

Figure 7 displays the parallel and perpendicular MMW reflectivity data for the black-net sample. The combined absorbing and scattering character of the netting makes it an effective



(a) Parallel



(b) Perpendicular

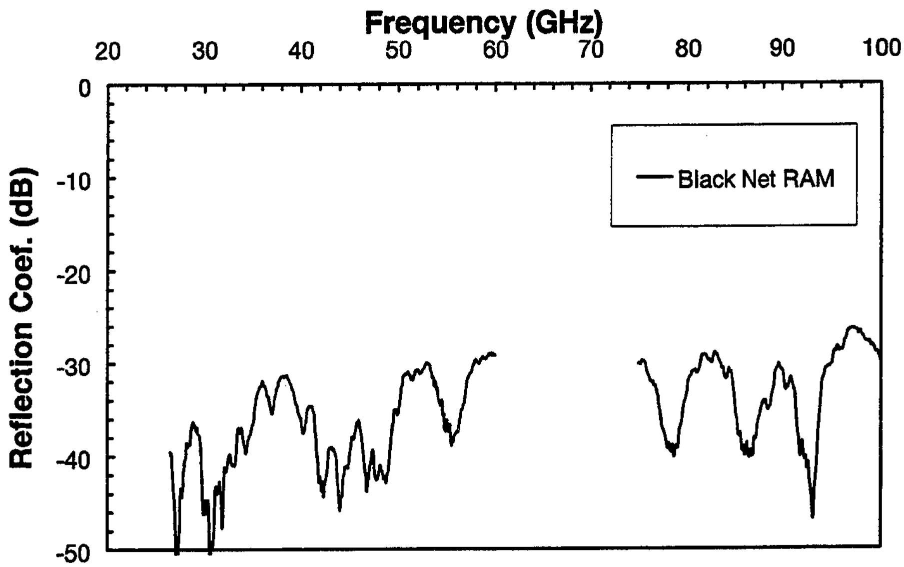
Figure 6. Reflectivity From 26.5–100 GHz for AAP ML-73 at 5° (Normal) Angle of Incidence.

radar-camouflage material, as its reflection coefficient is better than −30 dB over the entire frequency range.

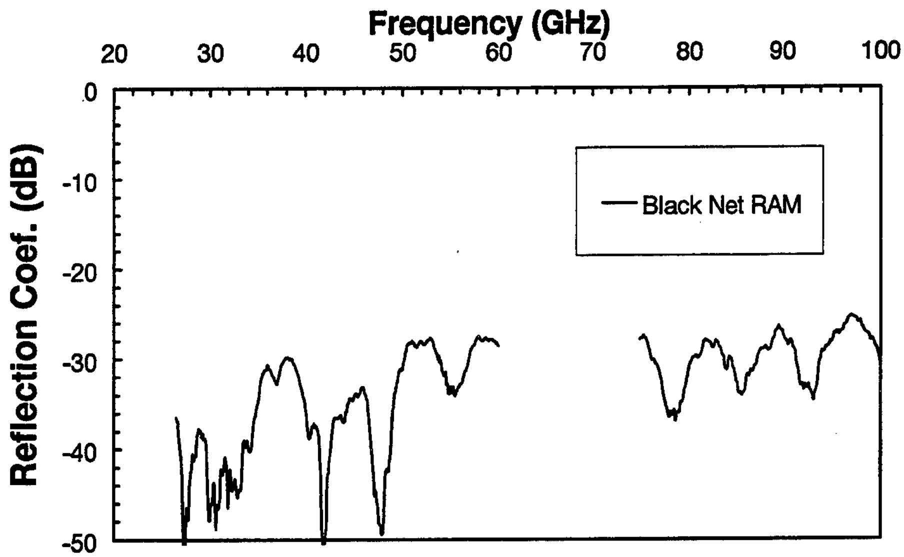
3.2 RAM Performance Results for Off-Normal (47°) Incidence. Figure 8 shows the reflection coefficient results for the AAP absorber sample when placed on one side of the dihedral sample mount. This results in an approximately 47° angle of incidence for the microwaves illuminating the sample, which, after exiting the sample, are reflected back to the receiving horn by the metal plate forming the second part of the dihedral [see Figure 5(b)]. The parallel and perpendicular reflection coefficient data are, again, similar, with an average absorption of more than −11 dB and absorption peaks at 35 (greater than −25 dB) and 86 GHz (greater than 21 dB), with respect to a metal plate in this configuration. Overall, the performance of this absorber is worse at this off angle, except at the frequencies noted.

The 47° angle of incidence reflection coefficient data for the black-net sample are displayed in Figure 9. The increased number of maxima and minima in the data are the results of interference effects due to multiple plate edges and joints present in the dihedral sample configuration. The average performance of the black net is about the same over the frequency range for both parallel and perpendicular orientations (better than 30 dB), with respect to a metal plate. This result would be expected for a thicker "net-type absorber," which works due to scattering and some absorption of the incident microwaves along the longer path through which the signal traverses through the material at the increased angle of incidence (~47°).

One other configuration was measured with the dihedral mount. Two 6- × 6-in samples of the AAP absorber with metal backing plates were mounted on each side of the dihedral. Figure 10 shows the performance data for the AAP dihedral. In this case, although the AAP absorber does not perform as well "off normal," the microwaves must pass through the material twice to be reflected back to the receive horn. The performance is better than −20 dB across the measured frequency range, with −40 dB or more absorption with respect the metal plates at the two peaks occurring at 35 and 86 GHz.

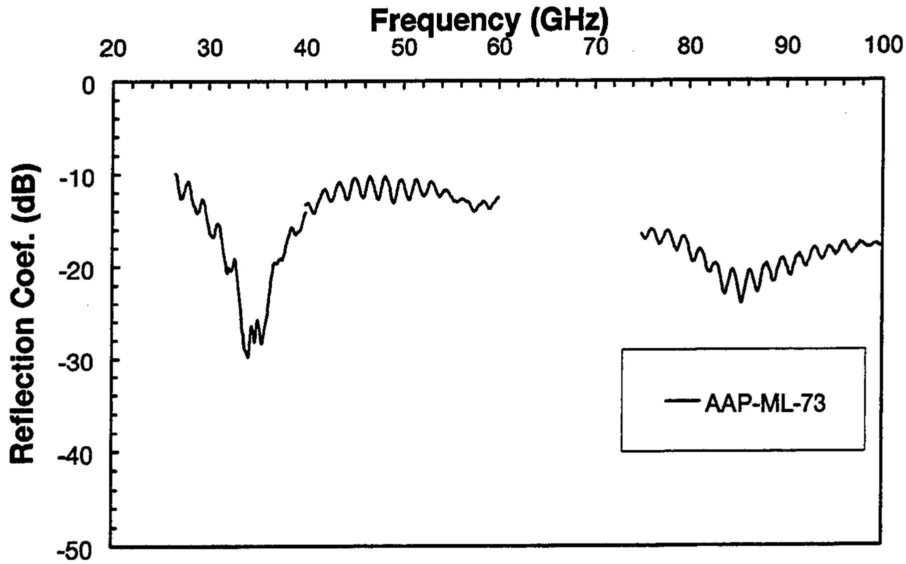


(a) Parallel

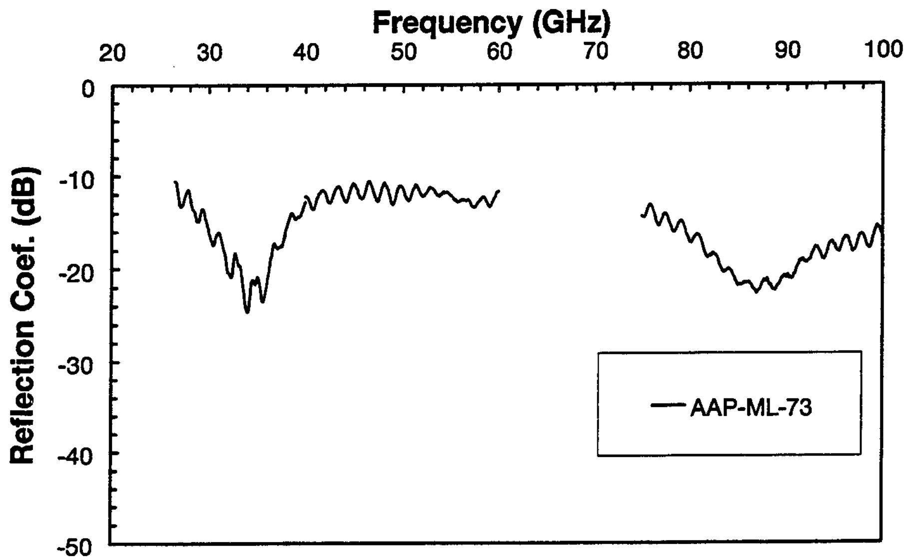


(b) Perpendicular

Figure 7. Reflectivity From 26.5–100 GHz for Black Net Sample at 5° (Normal) Angle of Incidence.

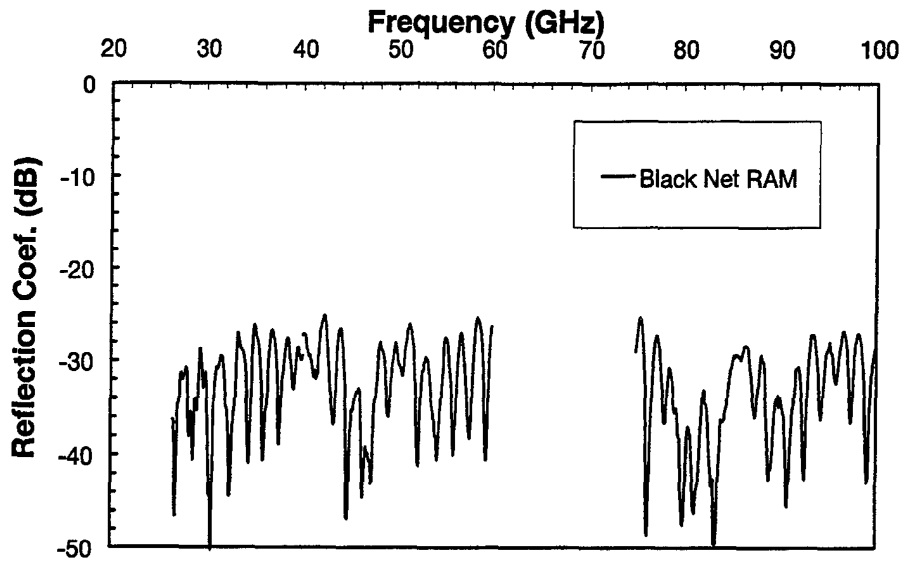


(a) Parallel

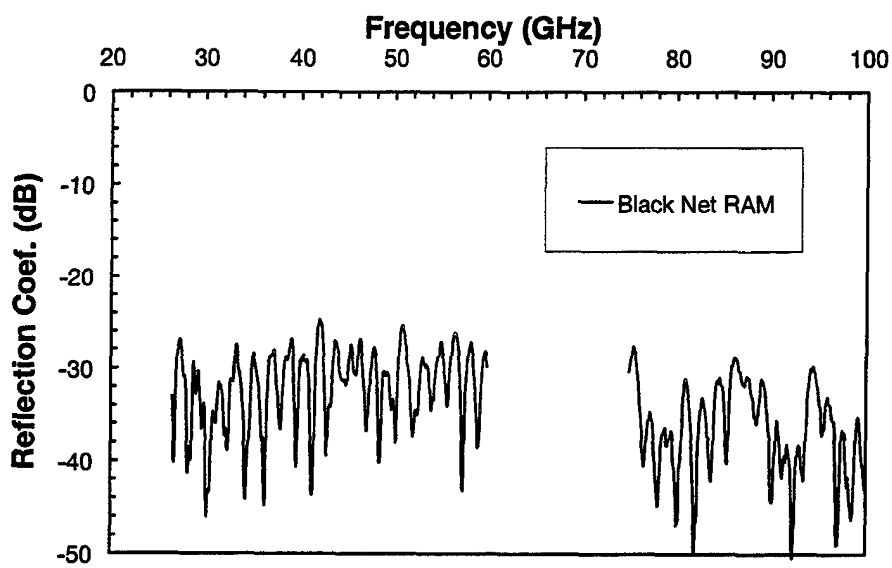


(b) Perpendicular

Figure 8. Reflectivity From 26.5–100 GHz for AAP ML-73 RAM at 47° (Off-Normal) Angle of Incidence.



(a) Parallel



(b) Perpendicular

Figure 9. Reflectivity From 26.5–100 GHz for Black Net RAM at 47° (Off Normal) Angle of Incidence.

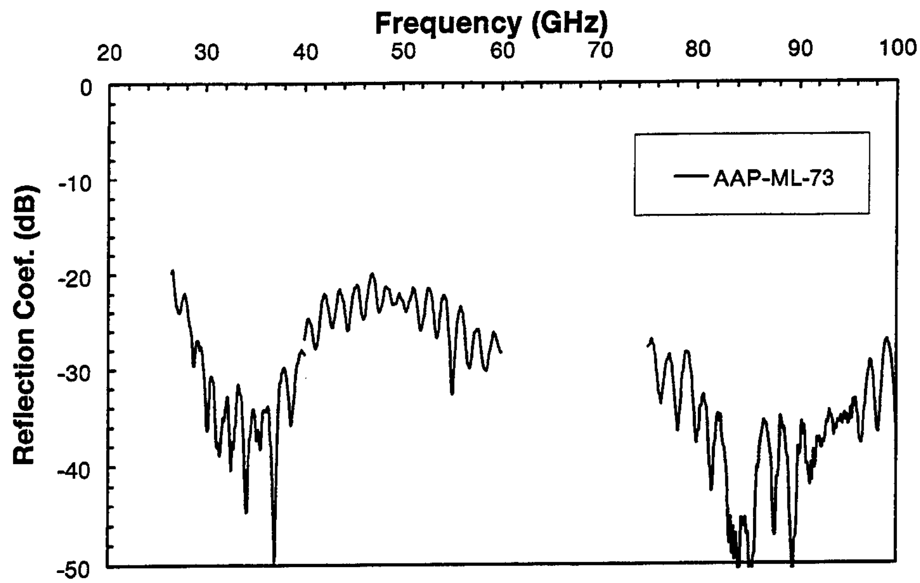


Figure 10. Reflectivity From 26.5–100 GHz of AAP ML-73 RAM Covered Dihedral at 47° (Off Normal) Angle of Incidence.

4. Conclusions

A comparison of the reflection coefficient data from the standard mount (near-normal incidence) with the data obtained with the sample on the dihedral mount (47° incidence) can be made for the two commercial sample types. This illustrates how differing RAM designs can vary greatly in performance at different angles of incidence of the radar signals. A RAM or RACO material to be utilized in camouflaging military systems with complex (not low observable) shapes should have good performance at normal angle of incidence and a sufficient performance at off-normal angles so that, in a double- or triple-bounce configuration, it performs as well or better than at normal incidence. A vehicle or aircraft designed from the start to have little or no complex shapes providing multiple bounces would not need a RAM or RACO material with this ability.

This novel and simple dihedral RAM sample test mount allows for testing the performance of RAM and RACO designs at off-normal incidence (~47°) and in a double-bounce configuration.

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U.S. Army Research Laboratory
ATTN: AMSRL-WM-MB
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13. ABSTRACT *(Maximum 200 words)*

A novel sample mount has been designed for making high angle of incidence radar-absorbing material (RAM) sample performance measurements. The sample mount allows for ~47° angle of incidence measurement of RAM millimeter-wave (MMW) reflectivity (performance). Measurements are taken from 26–60 GHz and 75–100 GHz in the U.S. Army Research Laboratory's (ARL) Weapons and Materials Research Directorate (WMRD) Composites and Lightweight Structures Branch (CLSB) anechoic chamber. RAM samples can also be mounted in a full dihedral configuration for simulation of RAM performance in double bounce (corner)-type locations. Performance of two commercial-type RAM materials was measured at close to normal and at the ~47° off-normal angles of incidence. A full dihedral covered with one of the commercial RAMs was also tested. The mount will allow for more realistic evaluation of ARL- and contractor-designed RAM and other coatings to be utilized in low-observable Army and Department of Defense (DOD) projects.

14. SUBJECT TERMS

radar-absorbing material (RAM), reflectivity, off-normal performance, millimeterwave (MMW)

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